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TECHNICAL NOTE

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INITIAL INVESTIGATION OF MONOPOLE ANTENNA SYSTEMS FOR USE ON SPHERICAL METAL SATELLITES

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SUMMARY

To obtain improved omnidirectional tracking, telemetry, and command communication coverage for future satellites, several monopole antenna systems were investigated with a view to minimizing nulls in the antenna pattern coverage. A conventional modified turnstile antenna used on spherical satellites, and various unconventional arrangements of feed and passive monopoles in pairs were investigated. Two different monopole arrangements provide a 10 db improvement in antenna pattern nulls as compared to the conventional turnstile. These results imply that the turnstile technique can be improved, and that the two systems recommended here are worthy of further consideration.

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INTRODUCTION

The investigations reported here were initiated originally with a view to providing an optimum antenna system for the NASA Atmospheric Structure Satellite (S-6) within the limitations of the original design concept. Since this concept included a conventional turnstile antenna system, and project planning had already proceeded on that basis, no radical departures from that basic design were considered. Shortly thereafter, the designers of this particular satellite finalized the original design. The work reported here was carried on independently, however, because of its potential usefulness in the designing of spherical metal satellites generally. The basic design parameters for the satellite may be summarized as follows: The satellite is to be a pressurized 35-inch sphere of stainless steel, and will have a spinning motion in orbit; the tracking frequency will be 136 Mc linearly polarized, and the telemetry and command frequencies will be respectively 136 and 120 Mc cross-linearly polarized.

The antenna investigations were conducted on a scaled down model (6.5 inches in diameter, or about 1:5.3) of the satellite, with a proportionately reduced wavelength ($\lambda/5.3$, or a frequency of 720 Mc). Four different monopole systems and a modified turnstile system were evaluated. In order to minimize nulls in the antenna patterns, and thus to improve the omnidirectional coverage, various unconventional arrangements of feed and passive monopoles were tried.

The spacing between monopole elements can cause the composite radiation pattern to vary appreciably from that of an ideal turnstile, which exhibits a more or less isotropic pattern. The null level of the radiation patterns can be determined from formulas which predict deeper nulls as monopole separation increases.* Earlier work by Dalle Mura and Schmadebeck (Private Communication) showed that the antenna cable harness could cause phasing errors between adjacent elements, resulting in voltage standing-wave reflections on the transmission or feed line. However, microdot module blocks may be used to standardize the assembly. These fittings connect the harness to the antennas and parallel

*Kraus, John D., "Antennas," New York: McGraw-Hill, 1950, pp. 57-67 the wires in the harness assembly. Tuning stubs are employed to reduce the voltage standing-wave ratios (VSWR) to about 1.1 or 1.2.

Polarization makes it very difficult to measure the radiation characteristics of monopoles which are arranged like a turnstile and also fed in phase quadrature. The mode of polarization changes from linear on the equator to circular on the poles and passes through elliptical modes in between; and the problem is further complicated by the fact that the circular polarizations are of opposite sense at the opposite poles. Thus, both the linear and the circular modes are measured and the results are interpreted accordingly.

SYSTEM I: FOUR ACTIVE MONOPOLES

In the first system tried, four active monopoles were spaced 90 degrees apart around the sphere's equator (Figure 1). The preliminary antenna patterns were measured with the antennas and harness used by Dalle Mura. However, analysis of these patterns showed this antenna system to be frequency sensitive. When the antenna elements were shortened to 90 percent of the calculated value, there was no noticeable change in frequency or VSWR mismatch, as shown by the new antenna patterns. The resulting pattern nulls ranged between 14.5 and 18 db below the maximum signal.

The four quarter-wave monopoles mounted on the equator were spaced 90 degrees apart physically and phased 90 degrees apart electrically (Figure 2a). The overall VSWR of the harness and the monopoles is 1.6 to 1.0. The equatorial plane patterns were measured at 720 Mc; no tuning stub was used.

The dashed line pattern of Figure 2 was measured with linear feed (horizontal dipole). The null depth, compared to the maximum pattern lobe, was 18 db. The solid line pattern was measured with a circular feed source,* and showed a maximum null depth of 14.5 db. The pattern symmetry and uniform null depths show that the anechoic chamber was relatively free of microwave reflections and that the test setup was in good operating order. A further effort to minimize the null depth of the patterns was undertaken with a two-monopole system.

SYSTEM II: TWO ACTIVE MONOPOLES

The second system tried consisted of only two active monopoles fed by a 720 Mc signal. The two adjacent elements were located 90 degrees apart physically, which is an improvement over the 180-degree spacing. The electrical phasing in the harness was varied from 90 to 180 degrees and the 180-degree phasing provided the best results. Both

*Taco parabolic antenna driver

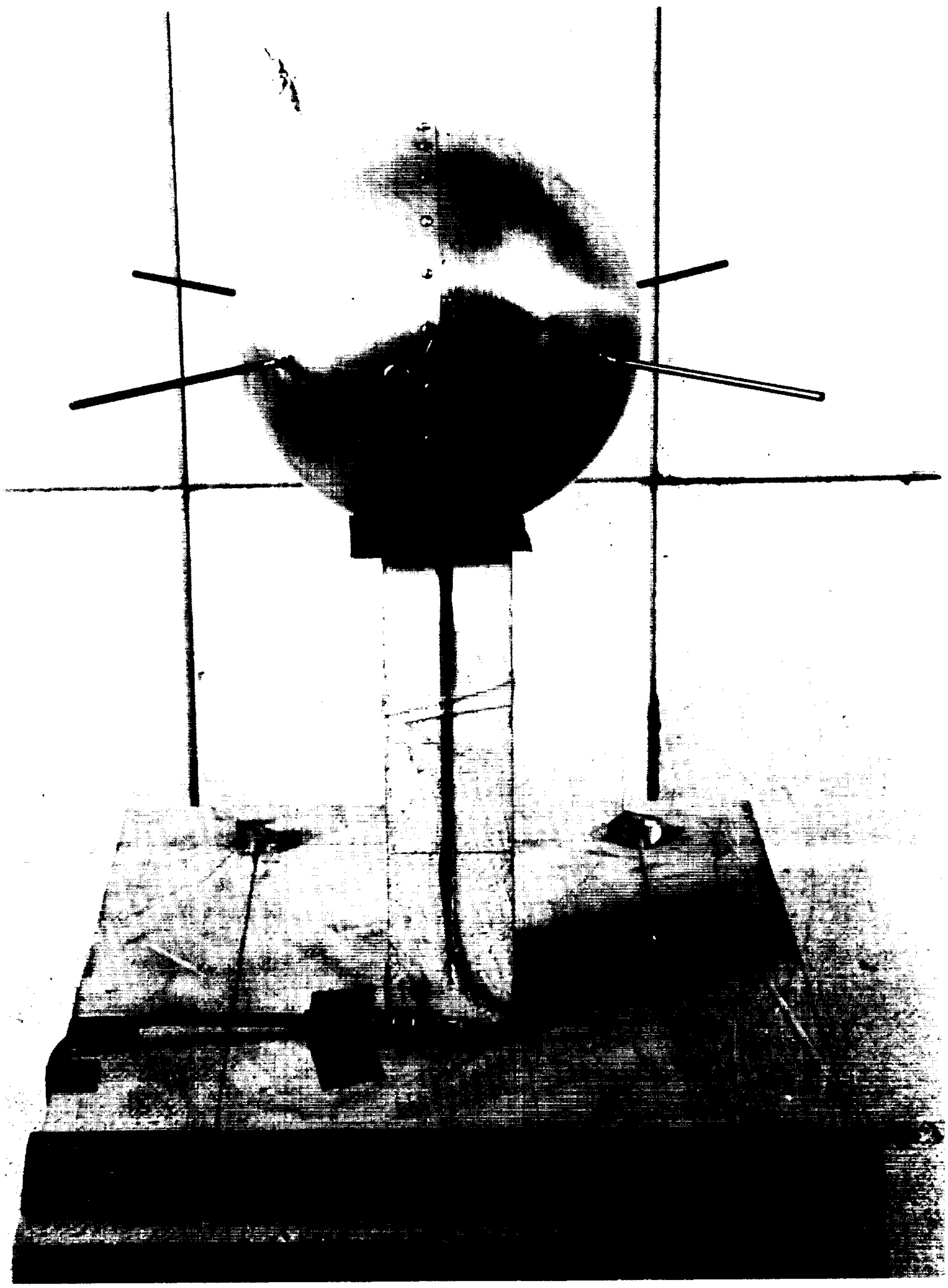
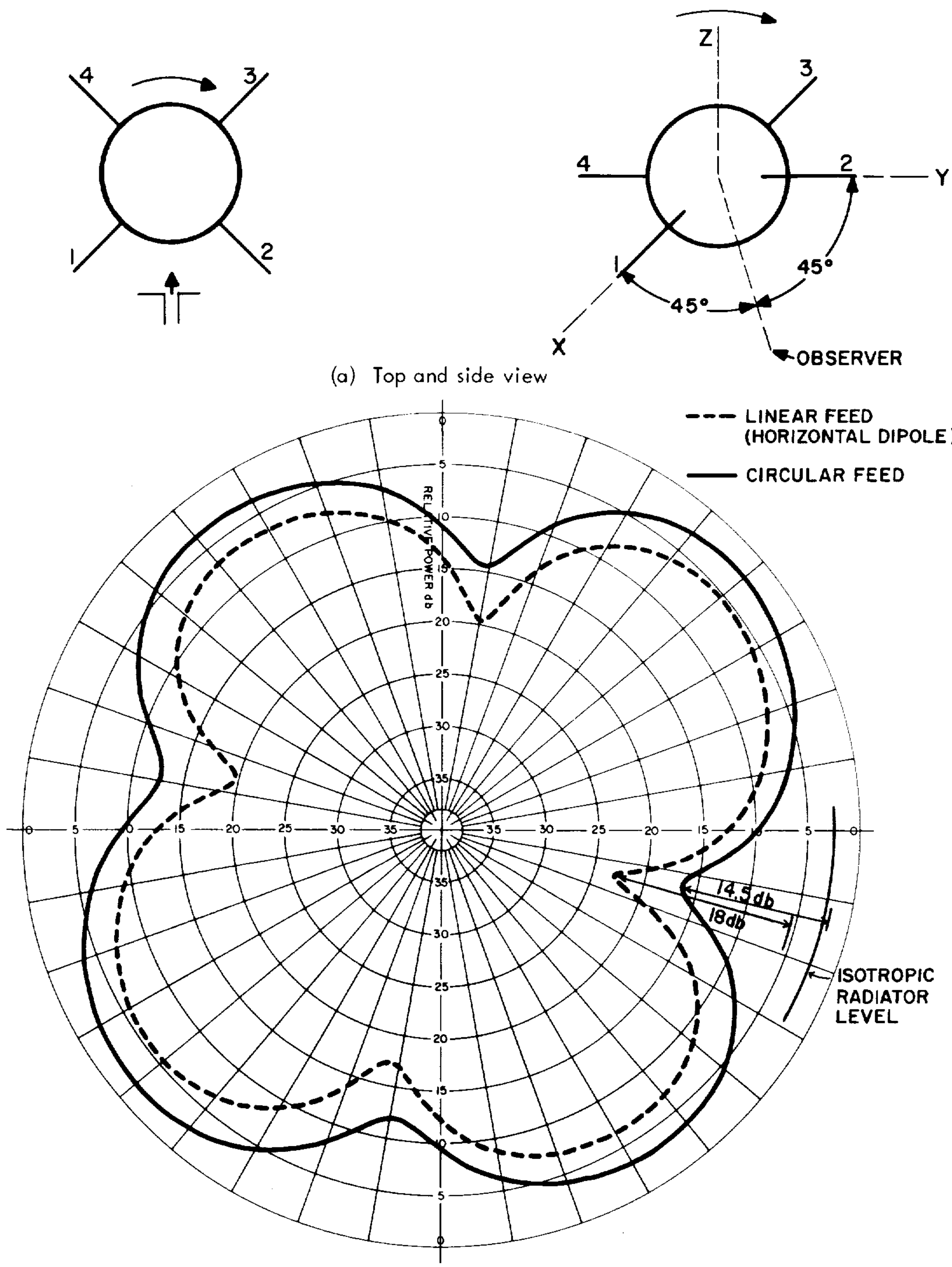


Figure 1 — Spherical scale model of satellite with four active monopole antennas



(a) Top and side view

(b) Equatorial plane pattern with 720 Mc linear and circular feeds

Figure 2 — Satellite model with four monopoles spaced 90° and phased 90° apart

circular and linear antenna feed sources were used to produce the patterns for evaluation. The best pattern had an 8-db null.

Equatorial Plane Cuts

Equatorial plane cuts were obtained by orienting the sphere so that the monopoles are positioned on the x and y axes. The sphere was then rotated in azimuth for an equatorial plane cut.

Figure 3a shows the sphere with the two monopoles spaced 90 degrees apart physically and phased 180 degrees apart electrically. Microdot "tee" connectors were used to construct the harness which was matched and stub-tuned to a VSWR of 1.26 for the overall system.

The equatorial plane pattern (Figure 3b, dashed line) measured with linear feed (horizontal dipole), had a 10-db null depth. This is an 8-db improvement over the comparable data in System I. The equatorial plane cut was repeated with a circular signal source (solid line pattern); and the resulting null depth of 8 db shows a 6-db improvement over the comparable pattern in System I.

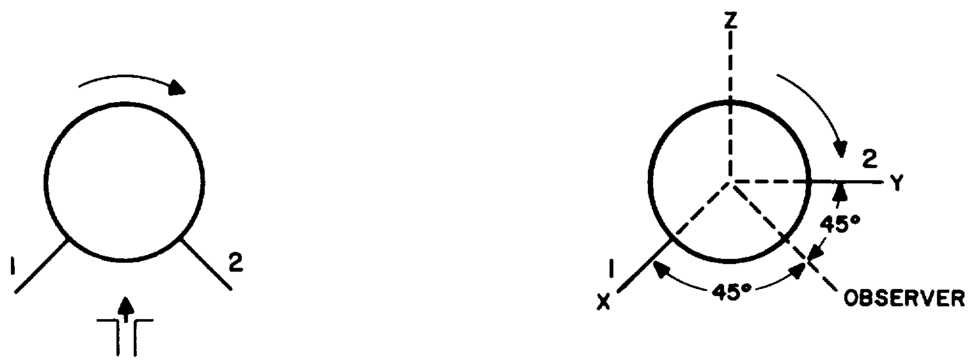
Polar Plane Cuts

Figure 4 shows both monopoles positioned 45 degrees from the vertical, with the polar axis in the xy plane. The sphere was then rotated in azimuth for pattern measurements. The dashed and dotted line patterns were measured with linear feed (the horizontal and vertical dipoles, respectively); their vector sum shows 6-db nulls. In the solid line pattern, null depths of 15 db suggest a phase interference resulting from the circularly polarized feed.

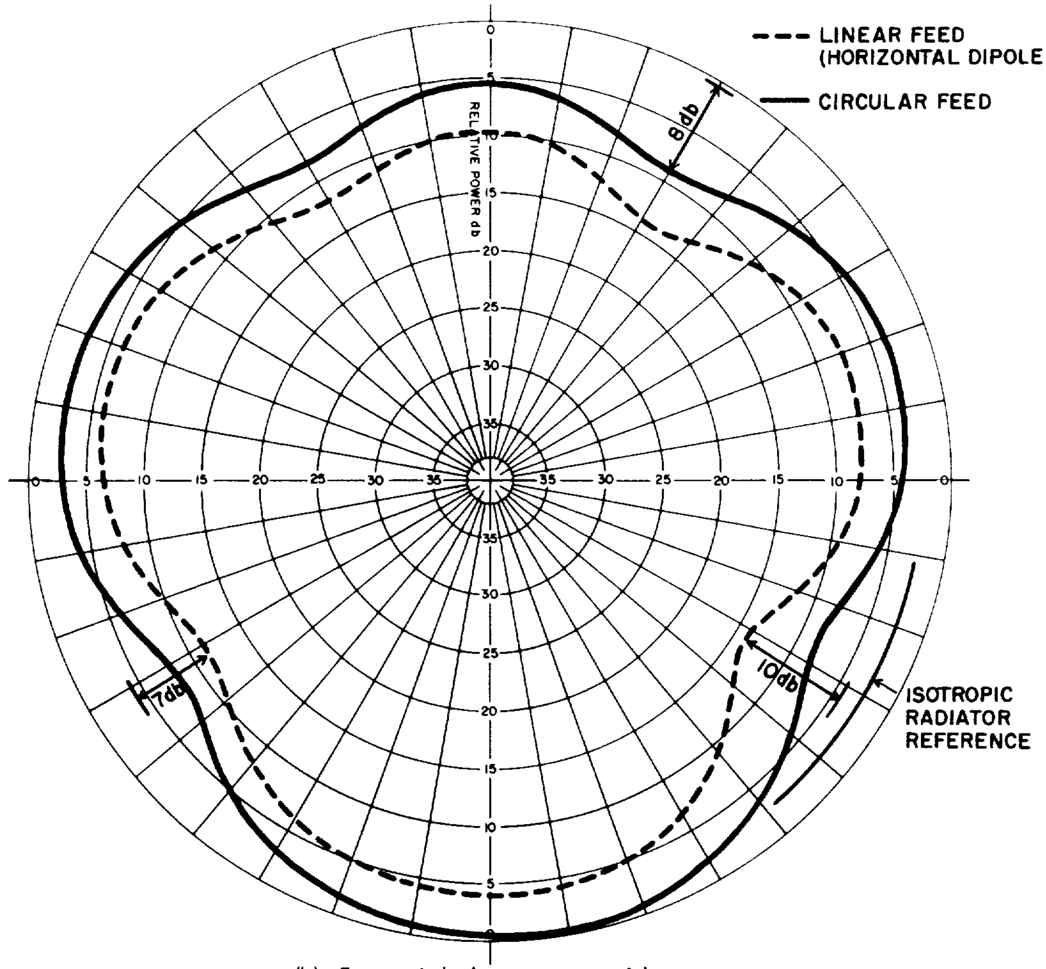
SYSTEM III: TWO ACTIVE AND TWO PASSIVE MONOPOLES

In the third system investigated, two active monopoles were fed by a 720 Mc signal, and two were passive, or parasitic monopoles. One active monopole (No. 1) was fed into a quarter-wavelength cable, and the other (No. 2) into a three-quarter-wavelength cable (Figure 5).

The two passive antennas fed into a 50-ohm load through half-wavelength cable harness sections and "tee" connectors. The antenna system had a VSWR of 1.1 and produced optimum patterns with very shallow nulls.



(a) Top and side view



(b) Equatorial plane pattern with
720 Mc linear and circular feeds

Figure 3 — Satellite model with two monopoles spaced 90° and phased 180° apart

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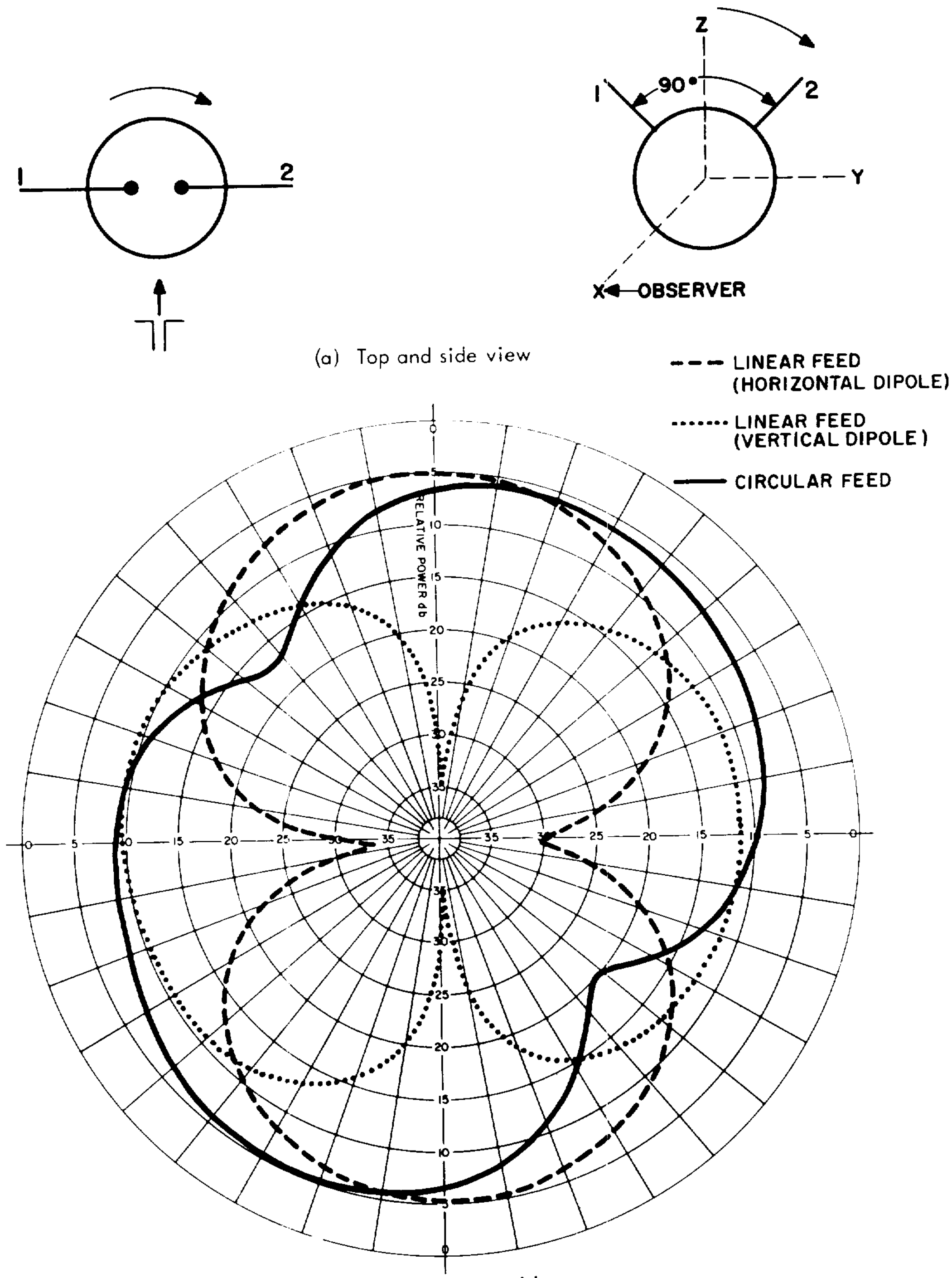


(a) Top and side view

(b) Polar plane pattern with 720 Mc/sec linear and circular feeds

Figure 4 – Satellite model with two monopoles spaced 90° and phased 180° apart

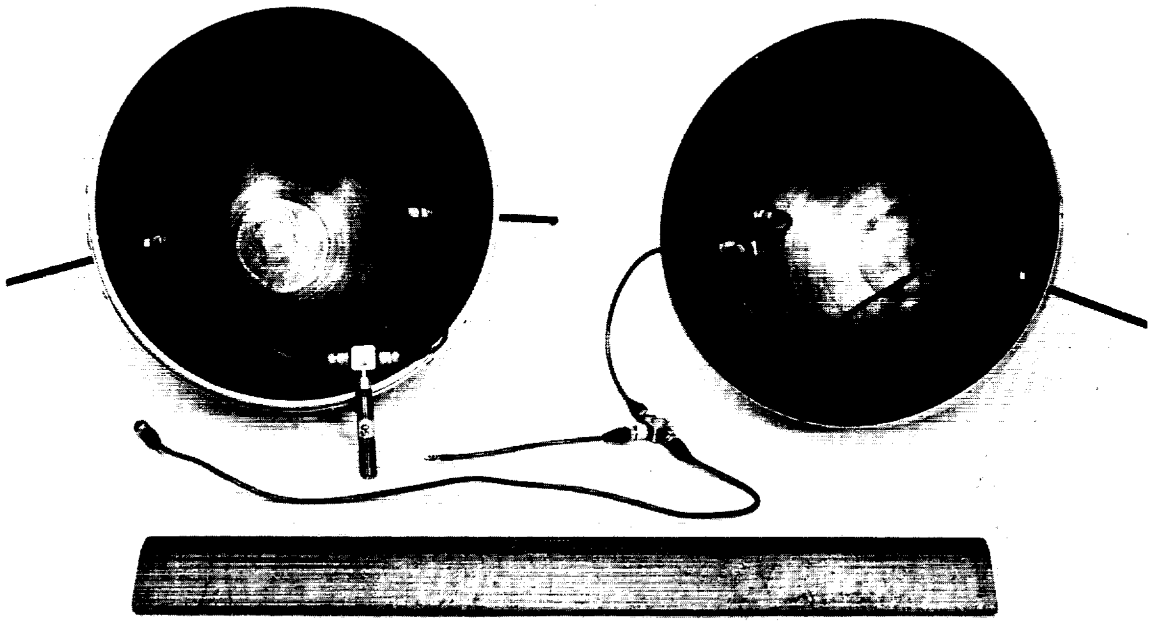


Figure 5 — Opened sphere showing active and passive antenna harness

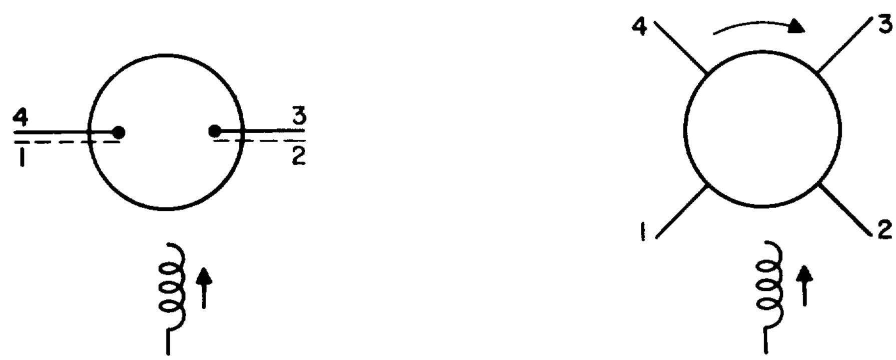
Equatorial Plane Cuts

The equatorial plane cut (Figure 6, dashed line), with a circular feed, had a null depth of 6.3 db. This is slightly better than the corresponding pattern for System II (Figures 3 and 4).

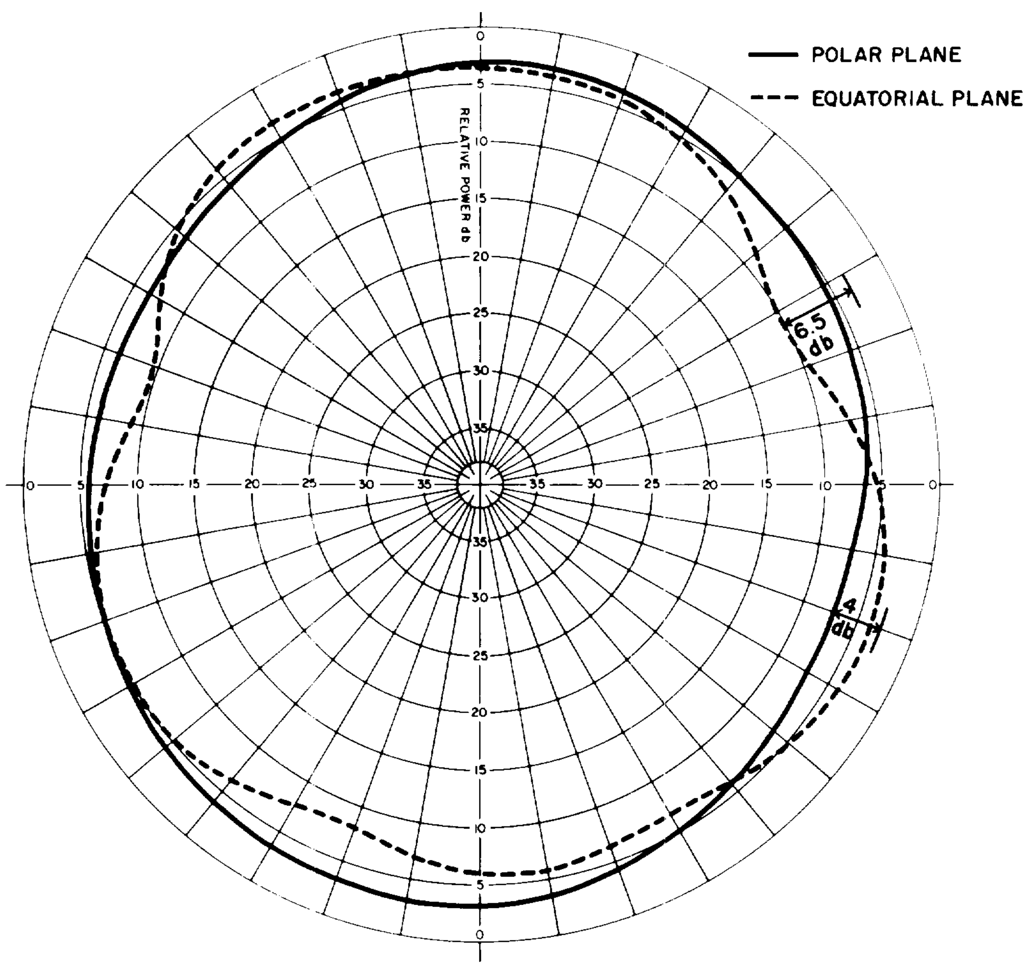
Figure 7 shows the resultant pattern when a linear feed (horizontal dipole) replaces the circular feed. The deepest null depth is 7 db, compared to the maximum pattern levels. The null is 6 db below an isotropic radiator reference circle.

Polar Plane Cuts

The polar plane cut (Figure 6, solid line), with a circular feed, produced a pattern with only 4-db null depths — a considerable improvement over the other patterns taken thus far. This pattern was confirmed (Figure 8) by recording a horizontal dipole pattern and a vertical dipole pattern. The vector sum of the horizontal and vertical components gave a pattern with less than 3-db nulls, when compared to the isotropic radiator reference level.



(a) Polar and equatorial plane views



(b) Polar and equatorial plane patterns
with 720 Mc/sec circular feed

Figure 6 — Satellite model with two active monopoles spaced 90° and phased 180° apart, and two passive elements spaced 90° apart

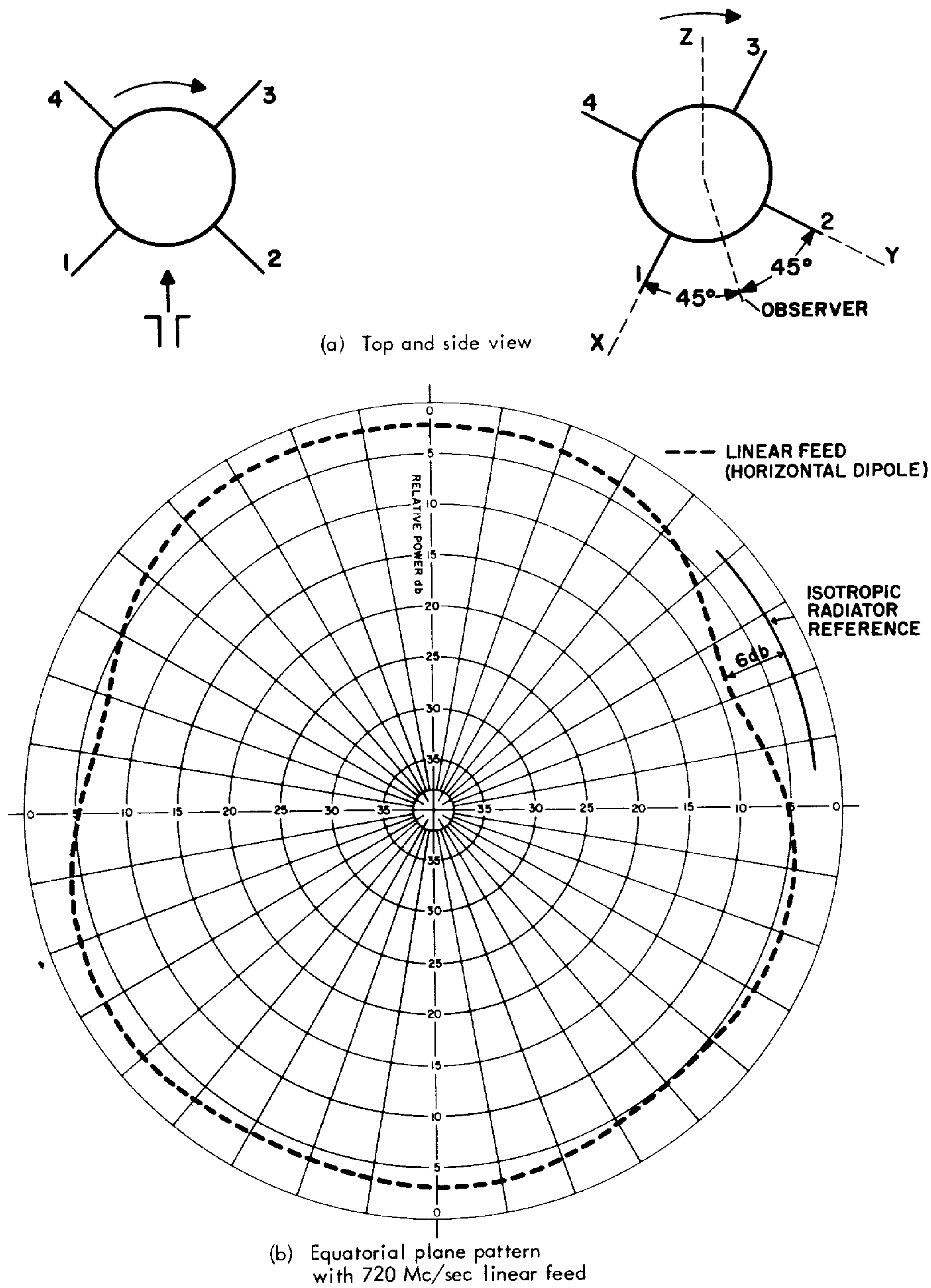


Figure 7 – Satellite model with two monopoles spaced 90° and phased 180° apart, and two passive elements spaced 90° apart

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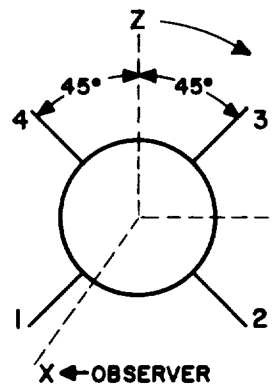
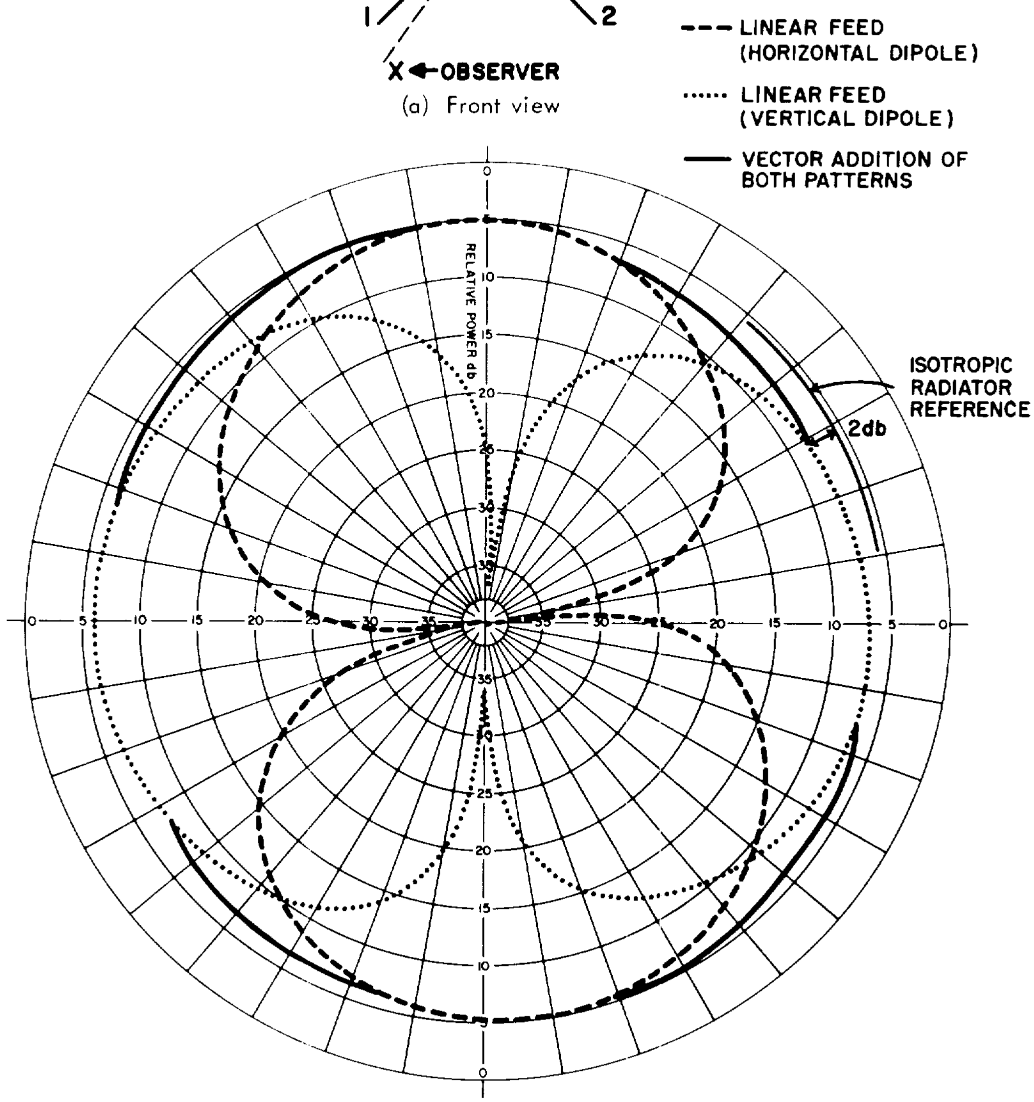


(a) Front view



(b) Polar plane pattern with 720 Mc/sec linear feed

Figure 8 — Satellite model with two active and two passive elements

Plane Cuts at 5-Degree Steps

Some of the other possible positionings of the satellite model were measured by tilting the model in 5-degree elevation steps from the position used in equatorial plane cuts to the position used in polar plane cuts. The null values varied from 5 to 30 db.

SYSTEM IV: TWO ACTIVE AND FOUR PASSIVE MONOPOLES

The final system employed six monopoles, two active and four passive (Figure 9), located on the x, y and z axes of the sphere, with the z axis corresponding to what has been previously designated as the polar axis. The six monopoles are connected as three separate pairs. The elements labeled x and y are fed together as the active elements 1 and 2 are in System III. The elements z and x' are passive, and are connected together in same manner as the passive pair in System III. Elements z' and y' are also connected as a passive pair. The only difference between this physical arrangement and the arrangement in System III is the addition of the two parasitic monopoles on the polar or z axis.

Equatorial Plane Cuts

The equatorial plane cut (Figure 10, solid line), with a circular feed, produced a pattern with a maximum null of 6 db. This is an improvement of 0.5 db over the equivalent pattern in Figure 6 for System III. The horizontal pattern (dashed line) with a linear feed (horizontal dipole) produced a pattern with a maximum null of 4.5 db — an improvement of 2 db over the equivalent pattern in Figure 7 for System III.

Polar Plane Cuts

The polar plane cut (Figure 11, solid line), with the circular feed, gave a maximum pattern null of 4 db, which is equal to the equivalent pattern in Figure 6 for System III. Both horizontal and vertical feeds were used to obtain patterns showing that the vector sum of horizontal and vertical components gives a pattern with less than a 1-db null compared to the maximum. This is 1 db better than the corresponding vector addition in Figure 8 for System III.

Other Plane Cuts

With the model positioned as shown in Figure 12, pattern nulls were measured by rotating the feed dipole 45°, 90°, and 135° from a vertical position. These nulls, which indicate that phase interference between elements was present for a relatively few satellite model orientations, are much lower than those of the similar model position and patterns

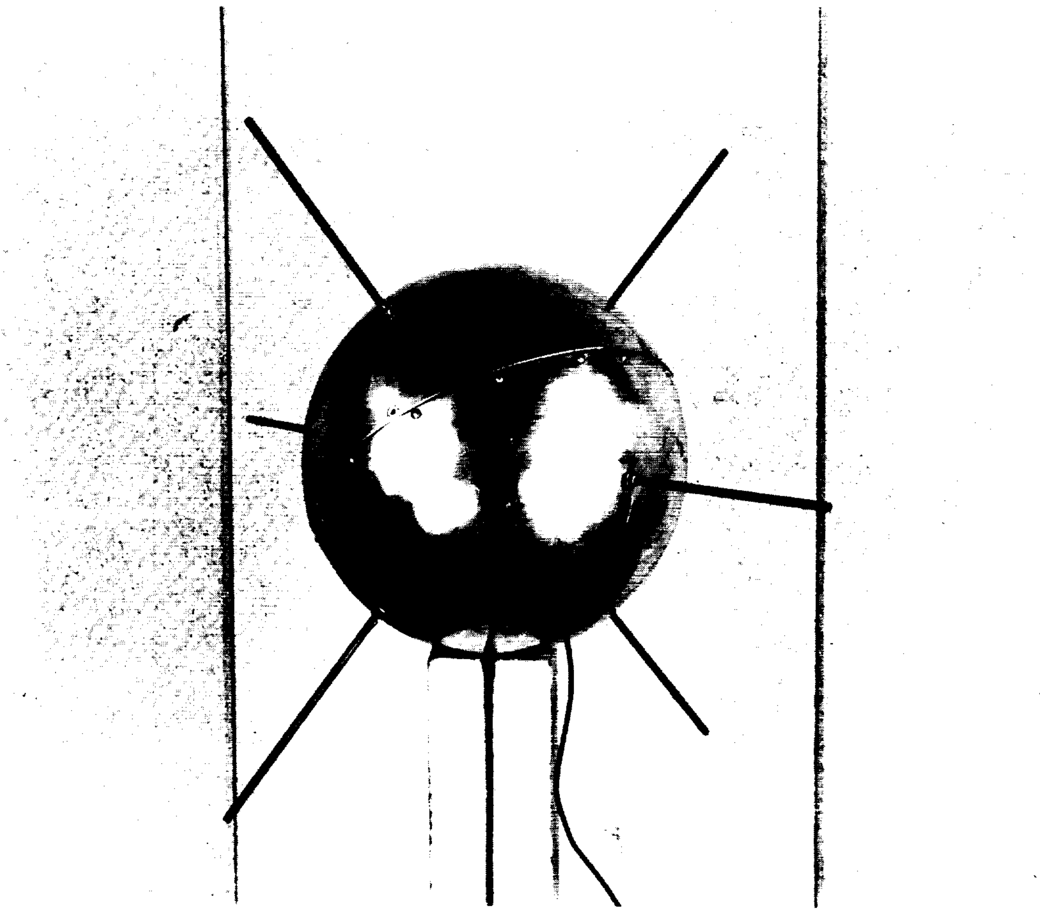


Figure 9 — Scale model of satellite with six monopole antennas

of System III. In another position of the model, the pattern nulls were never deep and give results superior to those for System III (Figure 13). Changing the model position again gave the patterns of Figure 14. The deep null obtained with the circular feed exemplifies the interference resulting from circular polarization of the opposite sense.

TURNSTILE AT POLE OF SPHERE

For comparison with the antenna systems described above, tests were made with a turnstile antenna located at the pole of the sphere (Figure 15). The arms of the turnstile were bent 45 degrees away from the plane tangent to the point of connection to the sphere. According to past antenna experience, this angle should be near the optimum. (Table I presents the data obtained for this and the four earlier systems.)

TABLE 1

Antenna Pattern Null Levels with Reference to an Isotropic Source

Antenna System	Feed Polariz.	Plane of Cut	Null Level (db)	
			Min. to Max. Signal	Min. to Isotropic
I	Horiz.	Equat.	-18	-20
	Circ.	Equat.	-14.5	-14.5
II	Horiz.	Equat.	-10	-12
	Circ.	Equat.	-8	-6
	Horiz.	Polar	-30	-30
	Vert.	Polar	-25.5	-30
	Circ.	Polar	-15	-15
	Sum of H & V	Polar	-6	-6
III	Circ.	Polar	-4	-2
	Circ.	Equat.	-6.5	-5
	Horiz.	Equat.	-6.5	-5
	Horiz.	Polar	-35	-35
	Vert.	Polar	-35	-35
	Sum of H & V	Polar	-2	-2 (vector sum)
IV	Horiz.	Equat.	-4.5	-5
	Circ.	Equat.	-5	-8
	Horiz.	Polar	-0.5	0 (vector sum)
	Vert.	Polar	-0.5	
	Circ.	Polar	-4	-7
	V,45°,H,135°,Circ.	Other	No numerical analysis	
	V,45°,H,135°,Circ.	Other	No numerical analysis	
	V,45°,H,135°,Circ.	Other	No numerical analysis	
Modified Turnstile at Pole	Horiz.	Polar	-29	-29
	Vert.	Polar	-10	-15
	Circ.	Polar	-9	-7.5
	Circ.	Turnstile 45° from Polar and Equatorial cuts	-27	-26
	Horiz.	"	-12	-12
	Vert.	"	-11	-14
	Circ.	"	-11	-10
	Horiz.	Equat.	-14.5	-16.5
	Vert.	Equat.	-15.5	-17.5
	Circ.	Equat.	-17	-17

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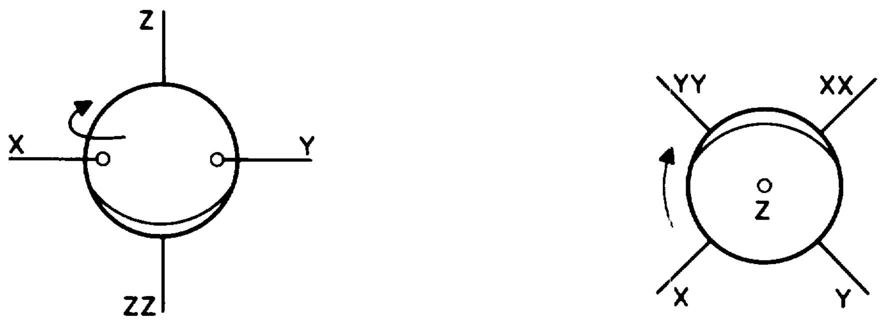
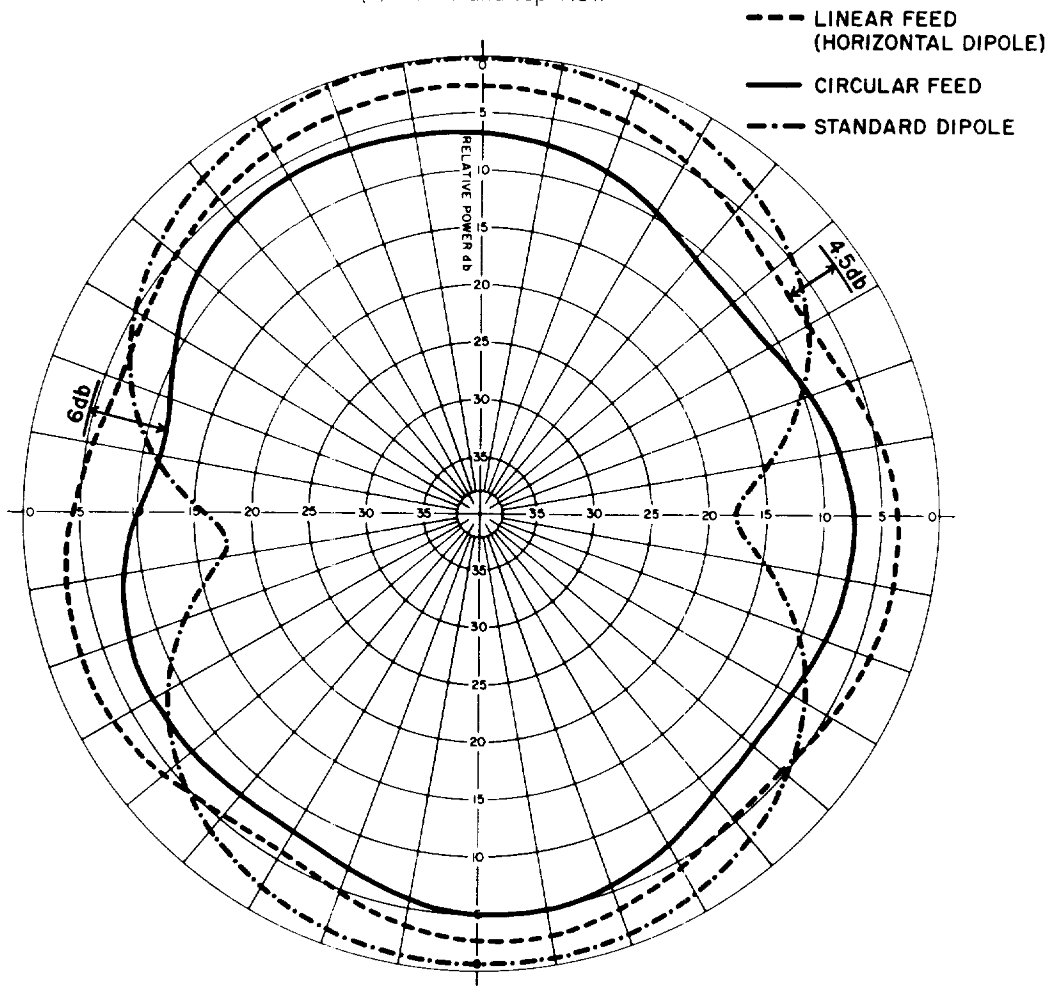
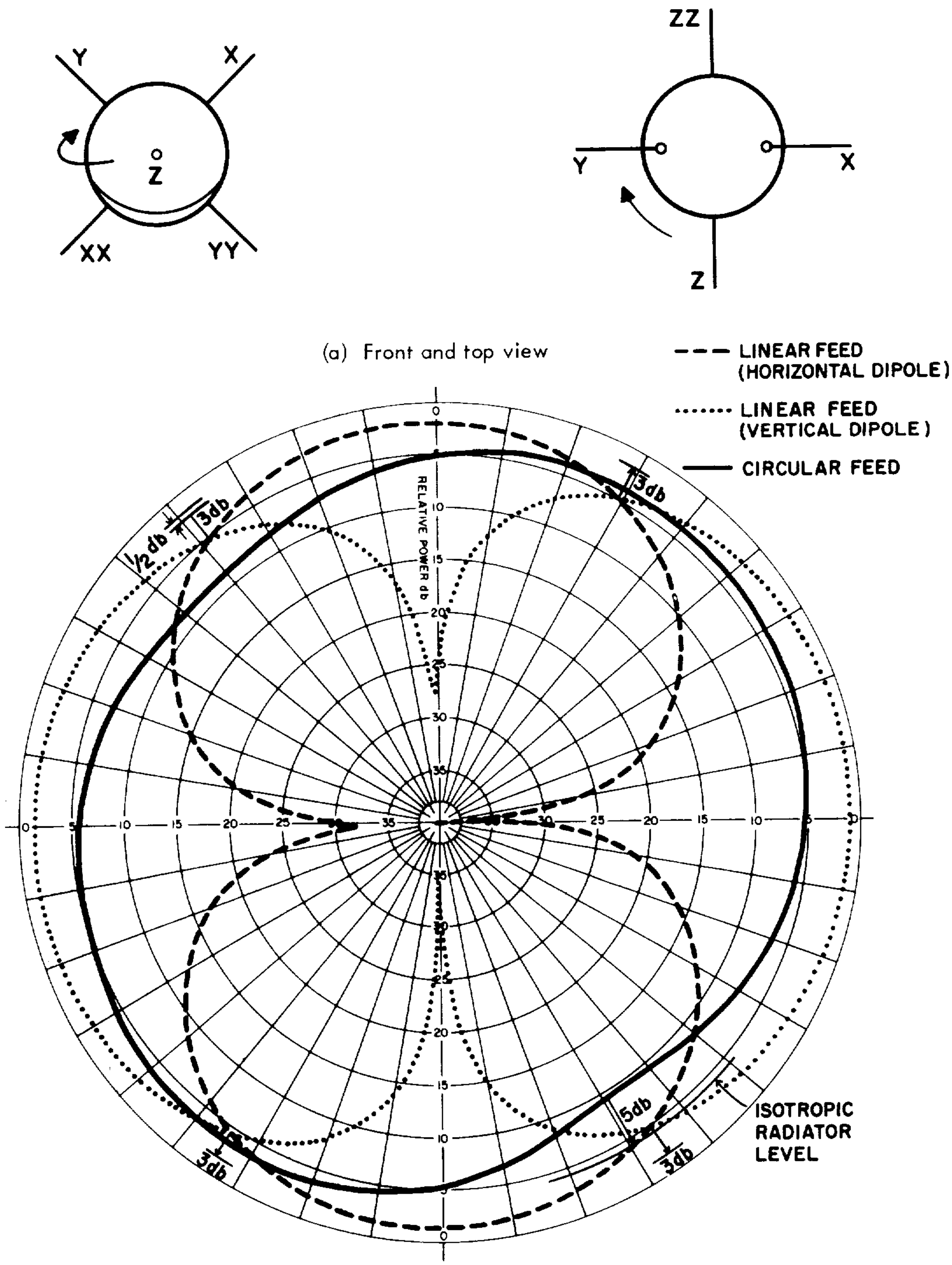


(a) Front and top view



(b) Equatorial plane pattern with
720 Mc linear and circular feeds

Figure 10 – Satellite model with six monopoles spaced 90° apart; one pair active and two pairs passive



(a) Front and top view

(b) Polar plane pattern with 720 Mc linear and circular feeds

Figure 11 — Satellite model with six monopoles spaced 90° apart; one pair active and two pairs passive

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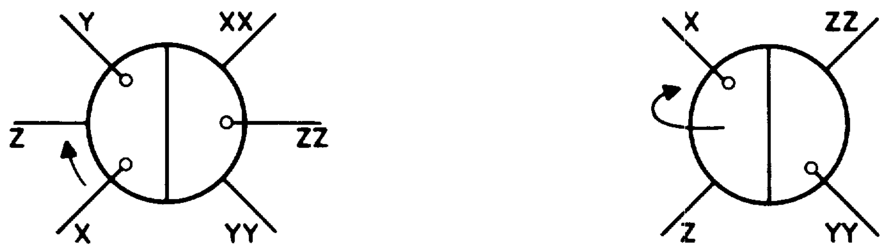
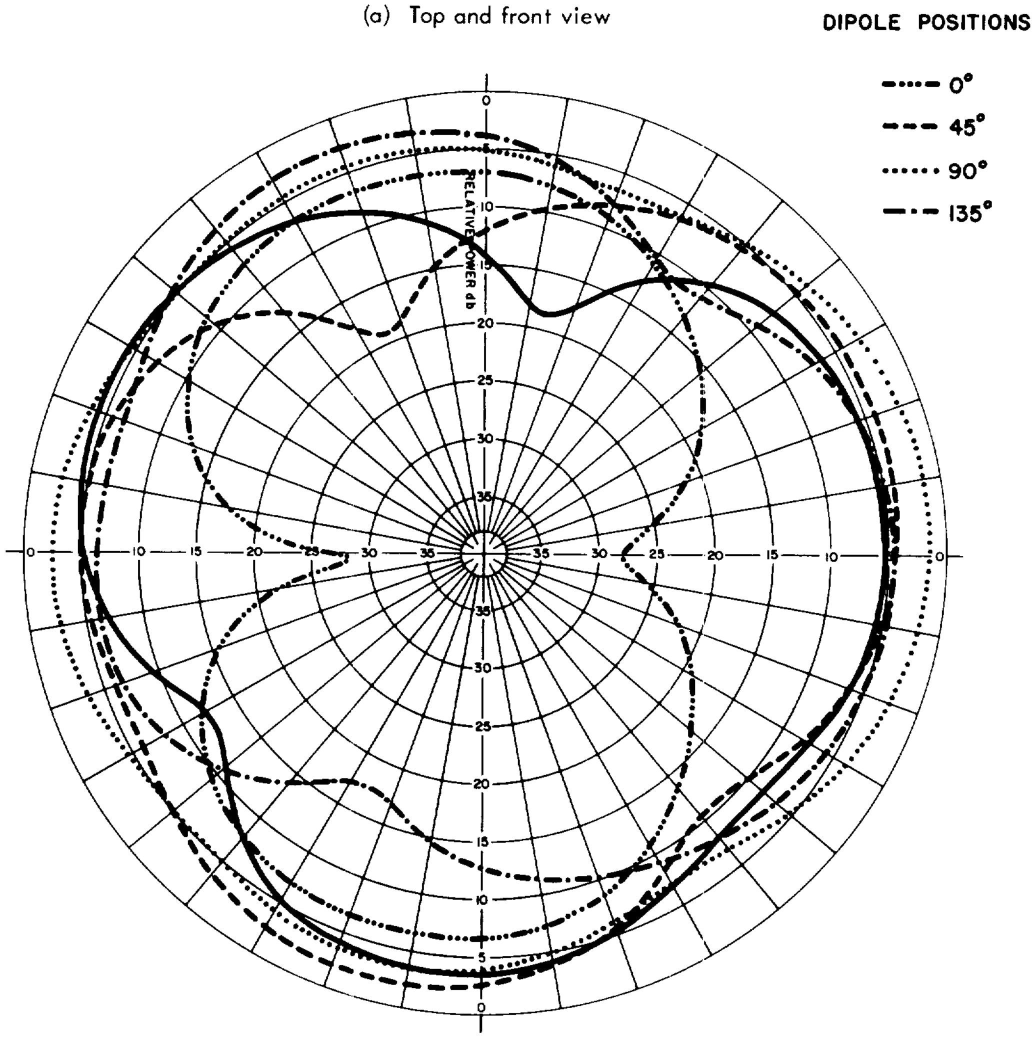
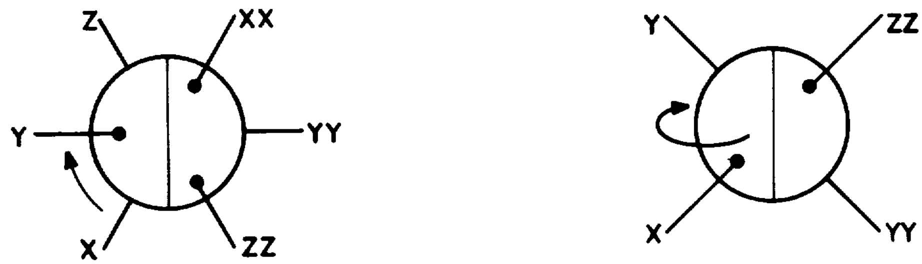


(a) Top and front view

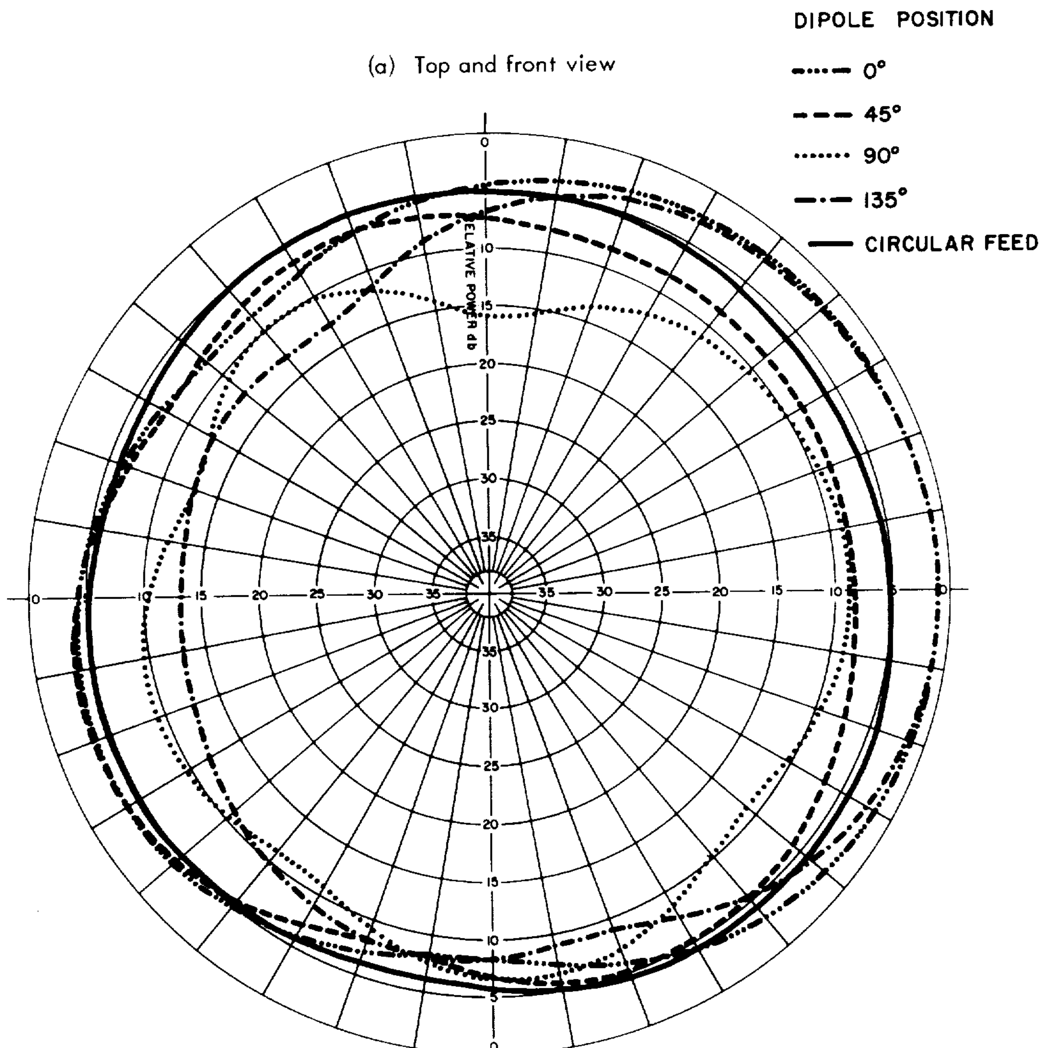


(b) Patterns made by rotating the feed dipole from a vertical position with 720 Mc linear feed

Figure 12 — Satellite model with six monopoles spaced 90° apart; one pair active and 2 pairs passive

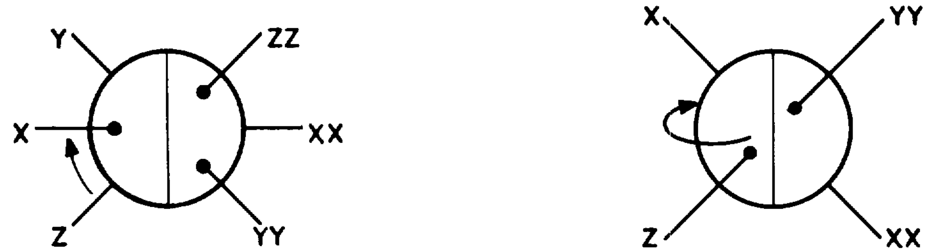


(a) Top and front view

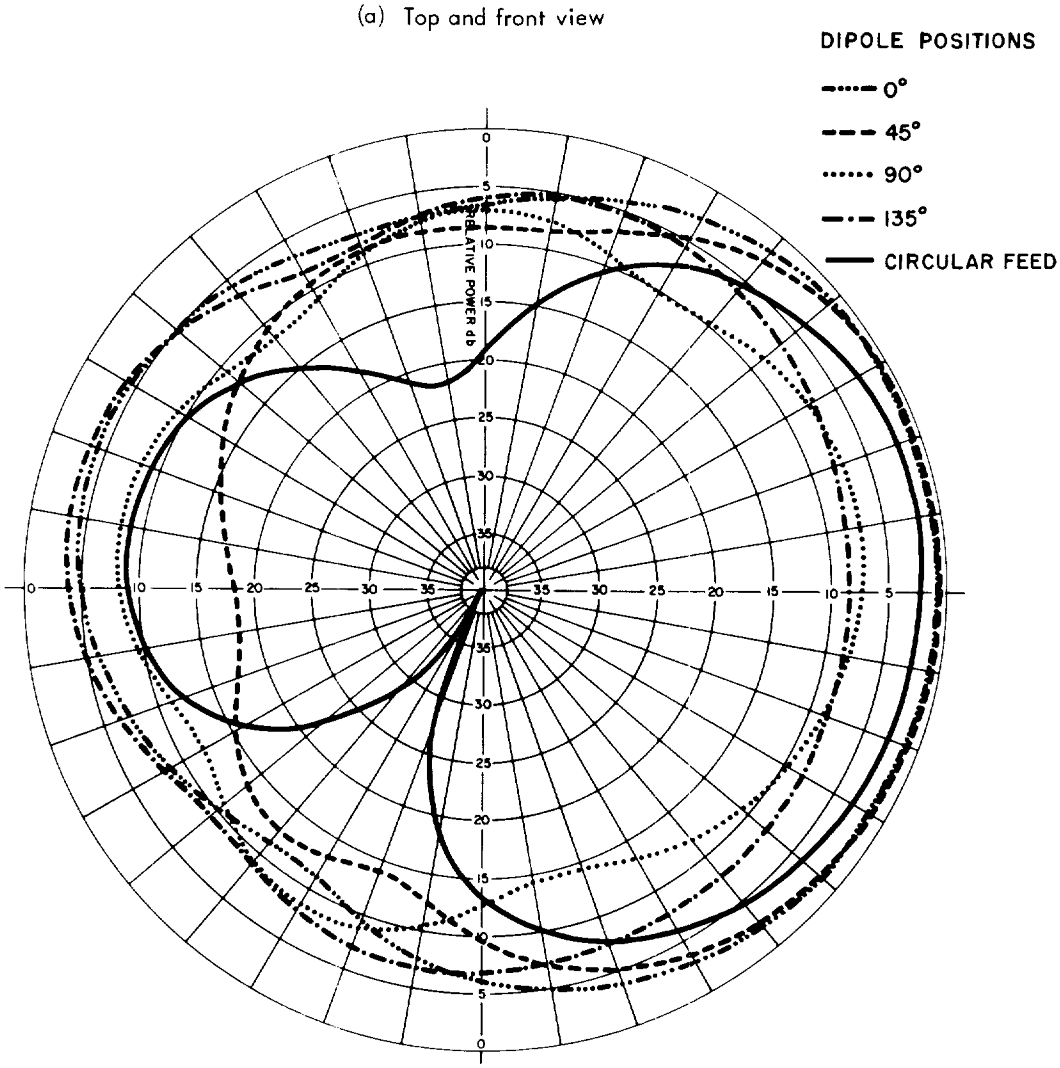


(b) Patterns made by rotating the feed dipole from a vertical position with 720 Mc linear and circular feed

Figure 13 — Satellite model with six monopoles spaced 90° apart; one pair active and two pairs passive



(a) Top and front view



(b) Patterns made by rotating the feed dipole from a vertical position with 720 Mc linear and circular feed

Figure 14 — Satellite model with six monopoles spaced 90° apart; one pair active and two pairs passive

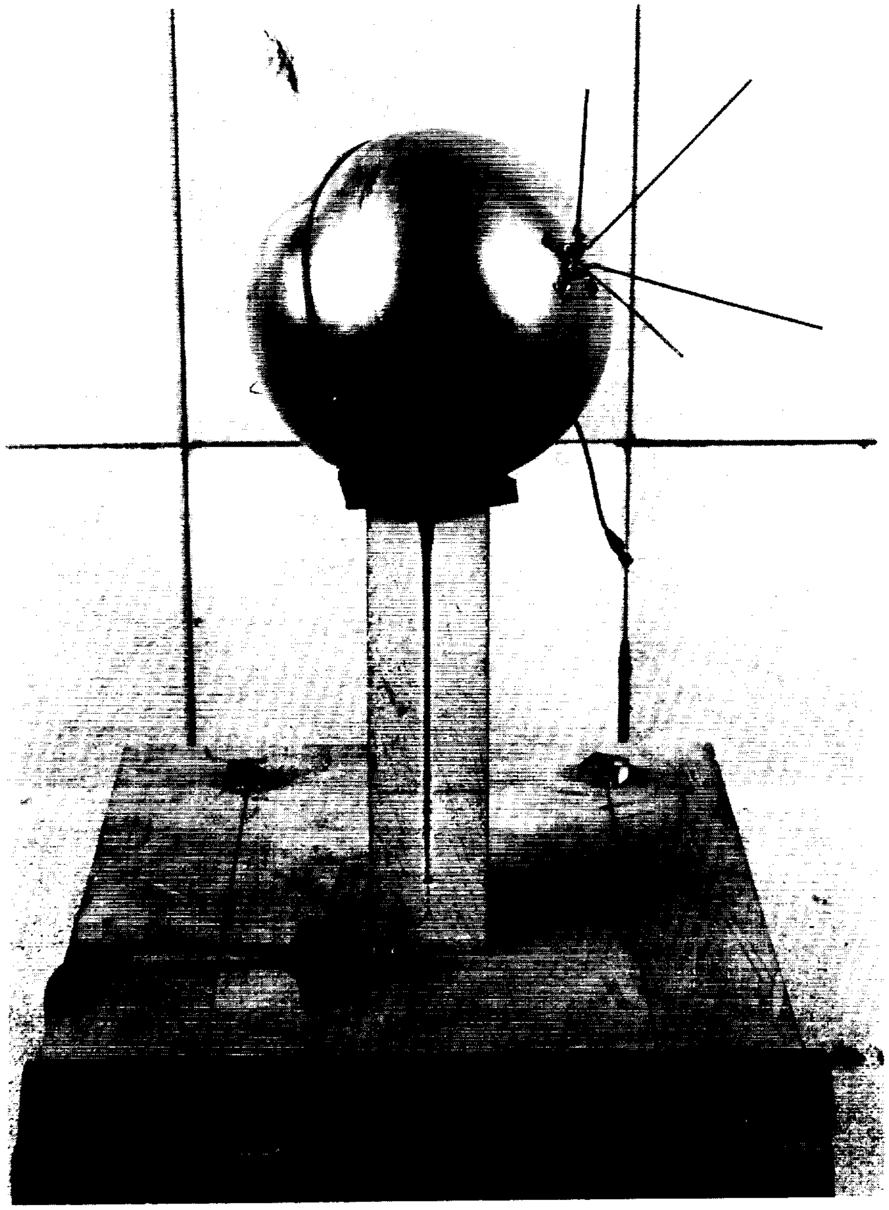


Figure 15 — Scale model of satellite with modified turnstile mounted at pole

The position arrangement for rotating the sphere with the turnstile mounted on the pole is shown in Figure 16. The pole axis rotated in a plane parallel to the ground; and the turnstile elements were phased 90 degrees apart electrically through a wiring harness into a Microdot tee module (Figure 17). This system was stub-tuned for a VSWR of 1.34 at 720 Mc. The polar patterns (Figure 16) resulting from horizontal dipole, vertical dipole, and circular feeds show nulls of as low as 30 db.

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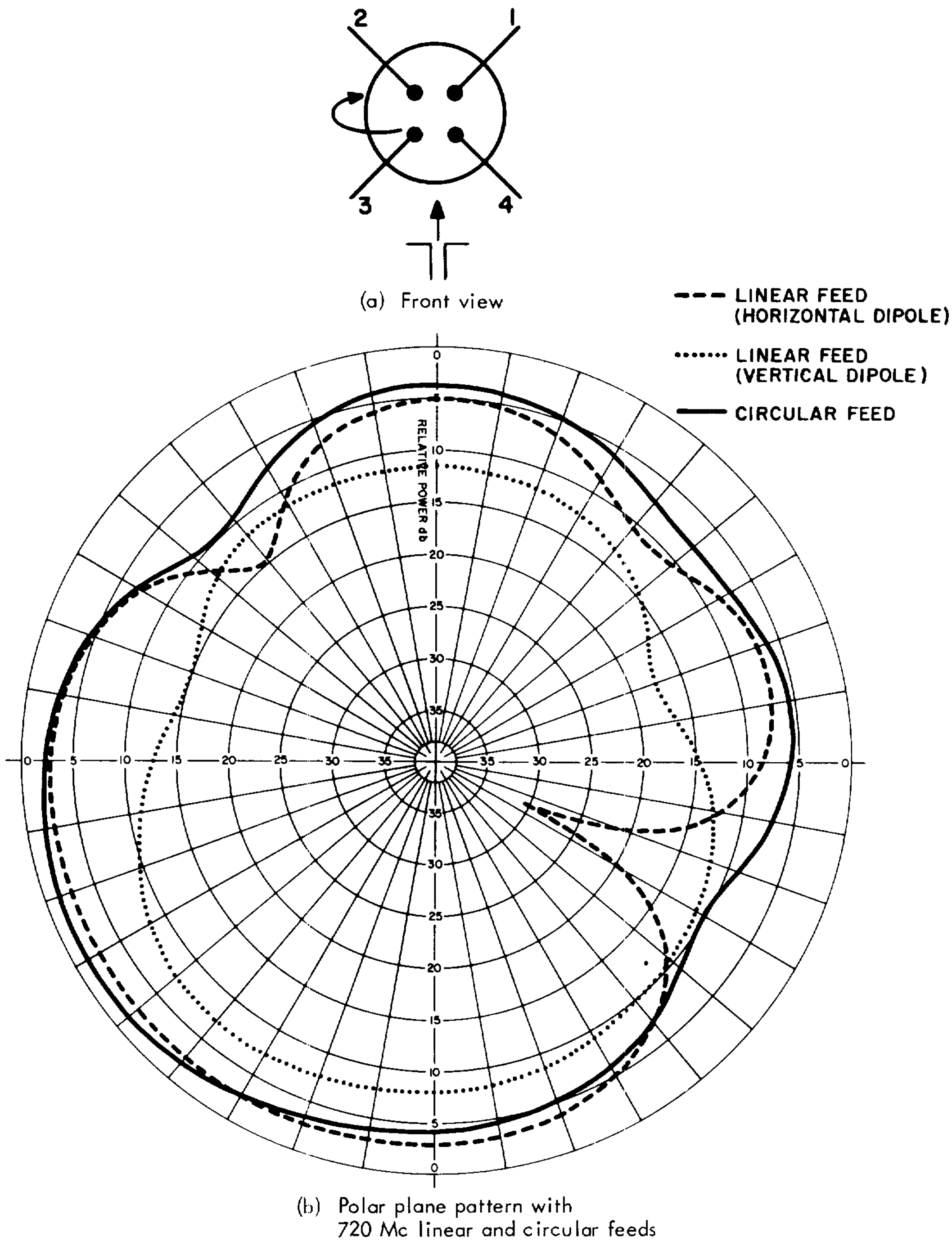


Figure 16 — Satellite model with four elements (turnstile) mounted on the pole of the sphere

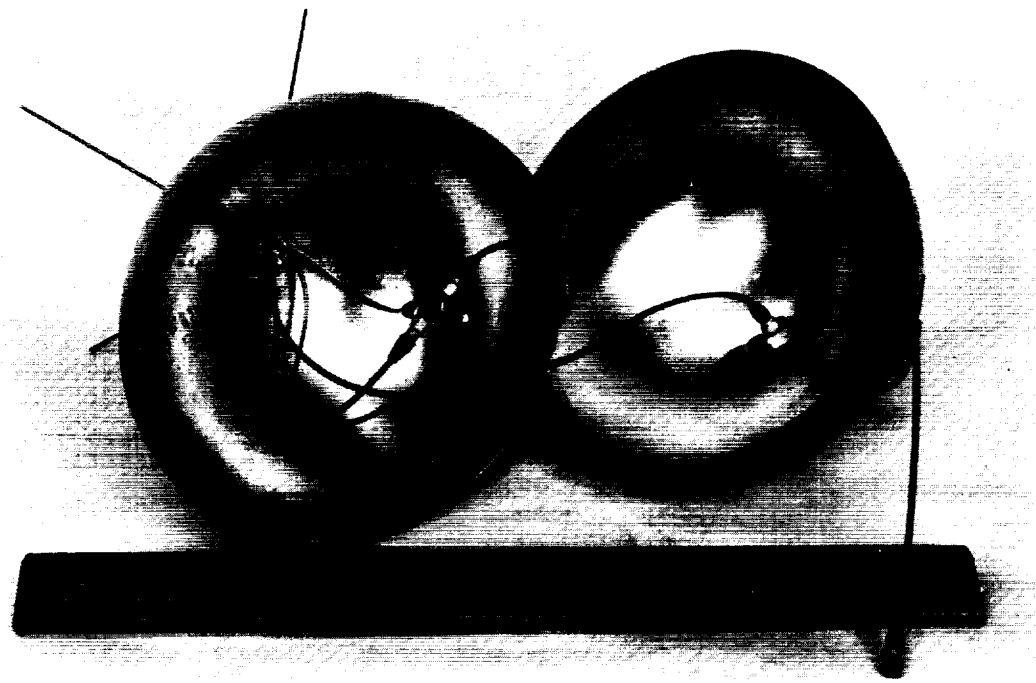


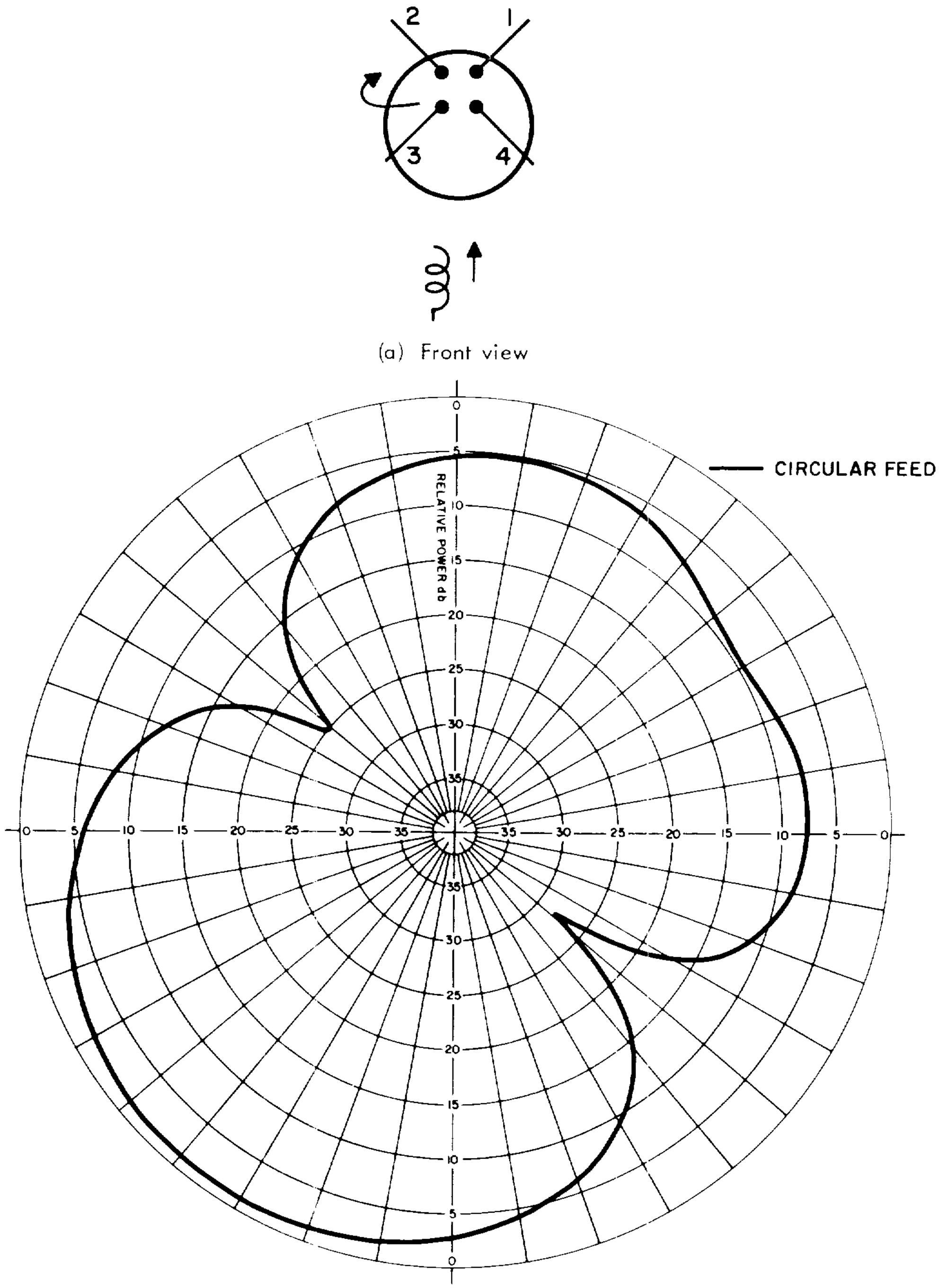
Figure 17 — Opened sphere showing phase harness and tuning stub

Figure 18 shows a circular feed pattern obtained by elevating the pole with the turnstile so that the polar axis was tilted up 45 degrees. The two deep symmetrical nulls, measured at 28 db, indicate a phase cancellation between the turnstile elements. This apparent cancellation was partially eliminated by turning the elements a half turn so that those numbered 3 and 4 were on top. The patterns recorded with circular feed, and also with horizontal and vertical dipole feeds have 12-db null levels (Figure 19).

Next, the sphere was positioned with the turnstile on top, and rotated about its polar axis. Patterns with nulls of 10 to 15 db were measured with horizontal dipole, vertical dipole and circular feeds (Figure 20).

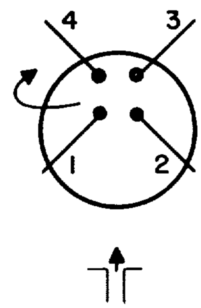
CONCLUSIONS AND RECOMMENDATIONS

The phasing problem of the conventional turnstile antenna as applied to spherical satellites has been demonstrated in the discussion of System I. This problem was successively reduced by Systems II, III, and IV. The antenna patterns of Systems III and IV show unusually good omnidirectional coverage, the only exception being the pattern deterioration due to circular polarization of the opposite sense. The improvement shown by the six-monopole System IV over the four-monopole System III is accomplished at the

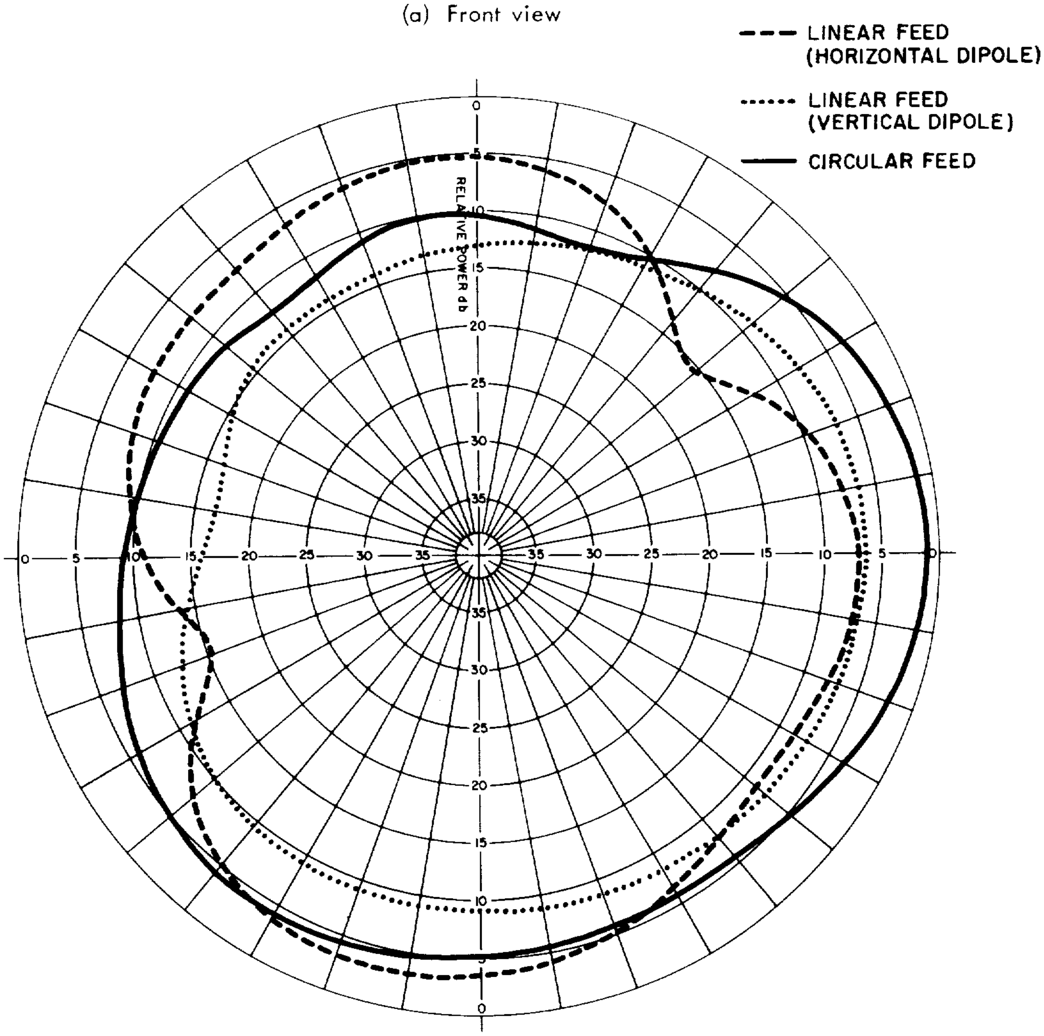


(b) Polar plane pattern with
720 Mc circular feed

Figure 18 — Satellite model with turnstile elevated 45° above the horizontal



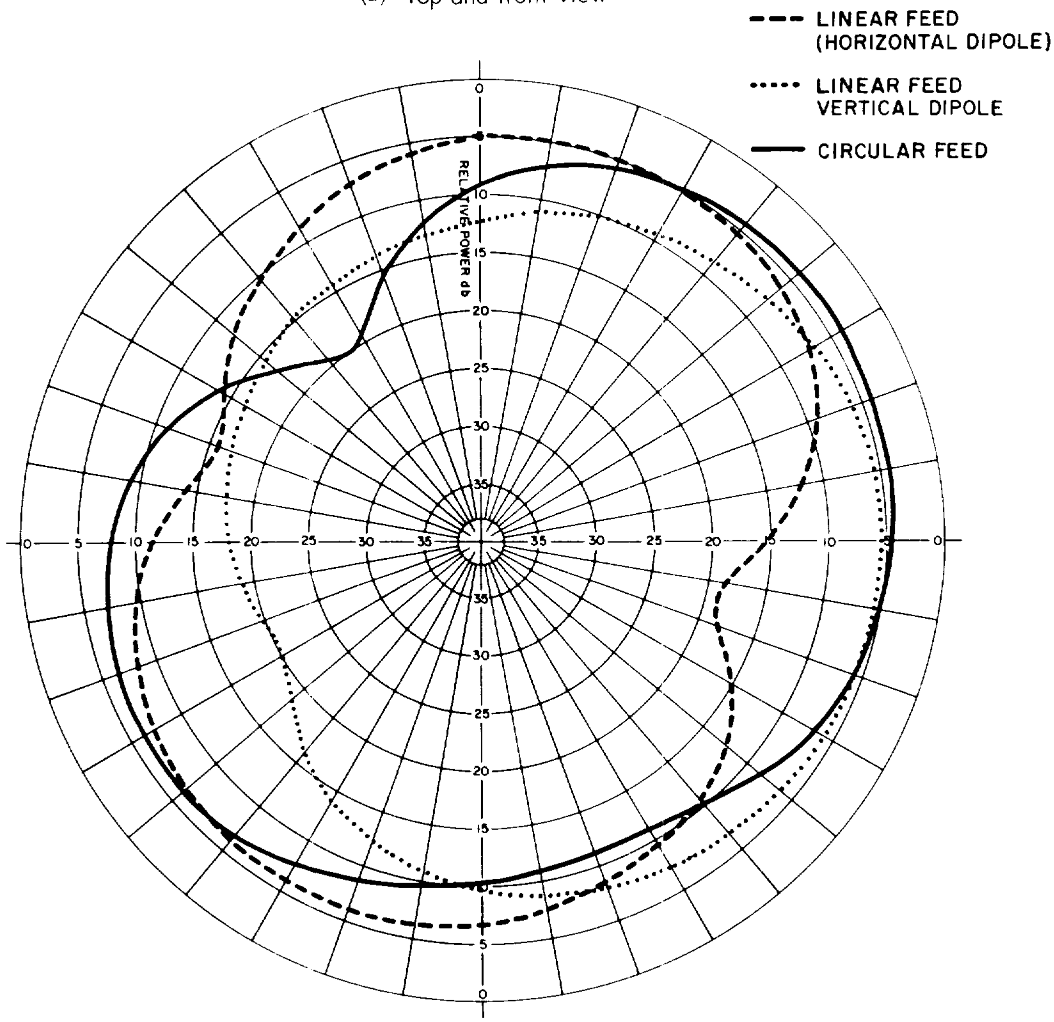
(a) Front view



(b) Polar plane pattern with 720 Mc linear and circular feeds

Figure 19 — Satellite model with turnstile elevated 45° above the horizontal and the sphere inverted 180°

(a) Top and front view



(b) Equatorial plane pattern with 720 Mc linear and circular feeds

Figure 20 — Satellite model with turnstile mounted on the pole of the sphere with the pole axis vertical

cost of a more complicated monopole arrangement; but this improvement of several db is desirable if the added complexity of the two extra monopoles is tolerable. The arrangement of a turnstile located at a pole of the sphere was also investigated but the patterns show it to be inferior to the monopole arrangements of Systems III and IV.

An array of four monopoles, two active and two passive, arranged at 90-degree intervals around the equator of the sphere is recommended for improving omnidirectional tracking, telemetry and communication coverage in the Atmospheric Structure Satellite. Two of the monopoles, spaced 90 degrees apart physically and phased 180 degrees apart electrically, would be fed by 136 Mc for tracking and telemetry. A tuning stub should be included in the wiring harness to minimize the VSWR. The monopole length should be 20.85 inches and the harness between the two elements should be 27.85 inches to maintain the 180 degree phasing. The other two monopoles would be fed by 120 Mc for command purposes, and should be spaced 90 degrees apart physically and phased 180 degrees apart electrically. The monopole length should be 23.60 inches and the harness between the two elements should be 31.50 inches for the 180-degree phasing.

Two separate harnesses and antenna systems would simplify the power transmission at both 136 Mc and 120 Mc, since the two circuits would be separate and completely isolated. A multiplexer or bridge matching network into a common antenna system could reduce the transmitted power by approximately 3 db.

In the event that an array of six monopoles may be placed on the satellite, this arrangement is recommended for optimum antenna pattern coverage. It would then be possible to obtain a more uniform omnidirectional coverage, and to have three completely separate, isolated circuits feeding the three independent sets of monopoles. This would permit placing the three separate transmitters or receivers close to the associated transmitting antennas, and thus might distribute the equipment weight more uniformly in the satellite structure.

NASA-Langley, 1962 G-142